Diesel/Solar Hybrid Power System – is it a Viable Option for Telecom Applications in the Arctic?

Barry Sugden
Manager, Infrastructure Planning
Northwestel Inc.
Whitehorse, Yukon, Canada
bsugden@nwtel.ca

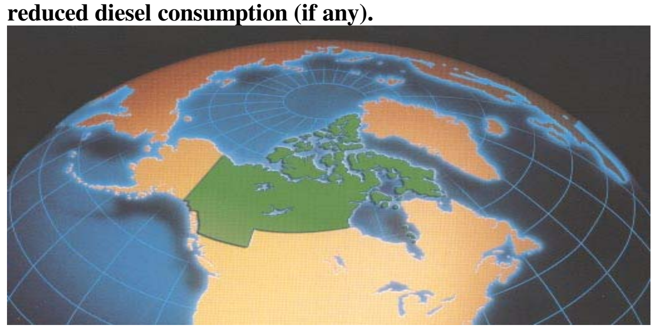
Abstract - **Northwestel is a Canadian based telecommunication company that currently operates over 100 "prime powered" sites supporting a microwave radio and fiber optic based telecommunication network. This network is located in some of the most rugged and sparsely populated geography on the planet, encompasses 3.9 million square kilometers of Canada's North, including the Yukon Territory, Northwest Territories, Nunavut, and Northern British Columbia.**

The operation and maintenance of the network repeater sites involves significant resources and expenses due to their remoteness. Access to approx 40% of the sites for quarterly maintenance and fuel delivery is via helicopter, which is very costly. Small scale 10-15 kW diesel generators, along with battery storage, is the system of choice for providing our "off grid" power requirements. This arrangement has provided the remote site energy needs for many years, while assuring an incredibly high level of reliability. However, given the financial realities of the Telecommunications industry today, with increased competition and shrinking margins, the need to reduce operating expenses is driving the search for innovative methods to produce power in a more cost effective manner.

The price of photovoltaic (PV) equipment has been greatly reduced in recent years, sparking the question of its potential use in Arctic regions. Integrating PV into Telecom power systems is nothing new, but is it practical in the Arctic, both technically and financially, given the dramatic variability of available solar resource, frigid temperatures, and ice & snow through a large part of the year?

In 2012, Northwestel partnered with Yukon's "Energy Solutions Center" and "Cold Climate Innovation Center" in a research project to test the viability of adding PV to an existing diesel powered site near the Arctic Circle, with the objective of determining the technical and financial viability of a Diesel/PV hybrid system. In 2013, a 15 kW PV system was installed at an existing mountain top microwave radio repeater site, along with data collection equipment to monitor energy production and site conditions.

This paper describes the Diesel/PV system installed, compares the "energy model" to "actual energy produced", discusses technical issues faced in the harsh Arctic environment, and reviews the viability of the business case based on the Capital cost of the system relative to the savings achieved through reduced diesel consumption (if any).



Northwestel's operating area

I. BACKGROUND AND DISCUSSION

In 2012, Northwestel and Yukon's Energy Solutions Center began discussing the potential of adding a PV array to an existing site already operating in "cycle-charge" mode. Based on the site load, an annual energy model was developed for various sizes of PV arrays. As well, a high-level cost analysis and business case was developed based on estimated PV array installation costs, the current cost of producing power with diesel, and the estimated cost of energy produced by a diesel/PV system. As the business case estimated a simple payback on Capital in approx 5 years, a project was initiated for the installation of the PV array in 2013, along with data acquisition equipment to monitor site conditions and power system performance.

The focus of this study is to validate the energy/financial models that predict that a diesel/PV highbred power system is a cost effective, reliable technology that can replace stand-alone diesel power systems at sites near the Arctic Circle (Lat 66' – 34" N).

Our research objectives include:

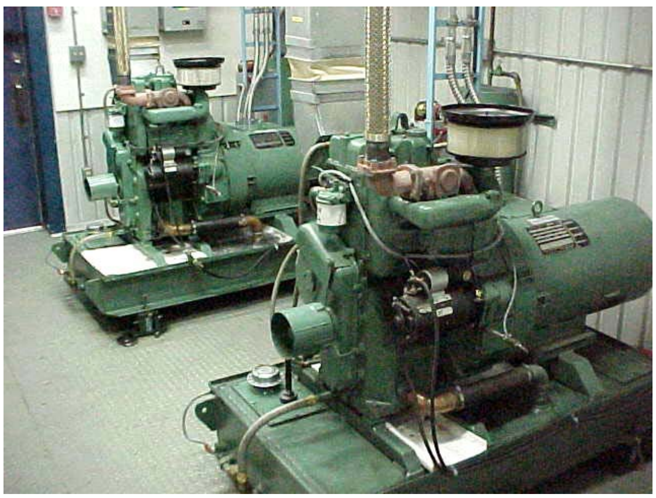
- Understand technical issues faced in construction, integration, and operation of the hybrid power system
- Validation of the energy production model
- Validation of the financial model/business case
- Apply "lessons learned" to subsequent hybrid power designs/systems.

978-1-4799-3104-0/14/$31.00 ©2014 IEEE

2. EXISTING POWER GENERATION SYSTEM

A. Power Generation Equipment

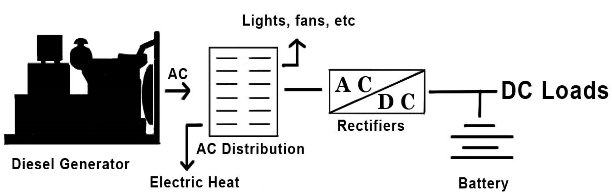
Air cooled diesel engines operating at 1200 RPM are used to minimize maintenance requirements and increase engine longevity. Depending on the site load, 1, 2, 3, or 4 cylinder engines are coupled to an alternator to produce AC power for the site. Typical site loads are between 2 – 3 kW, with some sites peaking at 15 kW. Redundancy is provided by a second engine, which will start automatically if the "prime" engine fails. Routine maintenance is performed on a quarterly basis by skilled power system mechanics to ensure that power availability of > 99.99% is maintained.


Typical 10 kW redundant diesel generators

B. Power System Modes of Operation

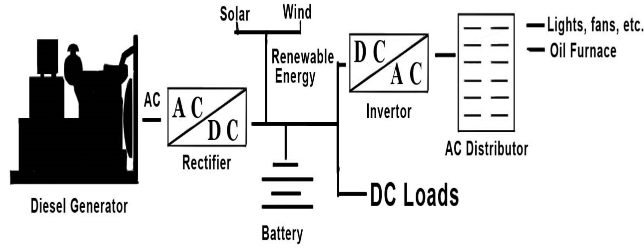
Several different operating modes are used:

- Prime; engine operates 24/7 to provide AC power to equipment (fans, lights, etc). AC/DC rectifiers are used to charge the station battery and power the DC telecom equipment.



"Prime" Power System Schematic

- Cycle-Charge; in an effort to reduce fuel consumption, a control system cycles the engine on/off to charge a large station battery. When the engine is off, the battery supplies DC to the telecom equipment, and a DC/AC inverter supplies AC to the fans, lights, etc. Renewable energy components (wind, solar) can be easily integrated with the Cycle-Charge system thanks to the common DC buss.



"Cycle-Charge" Power System Schematic

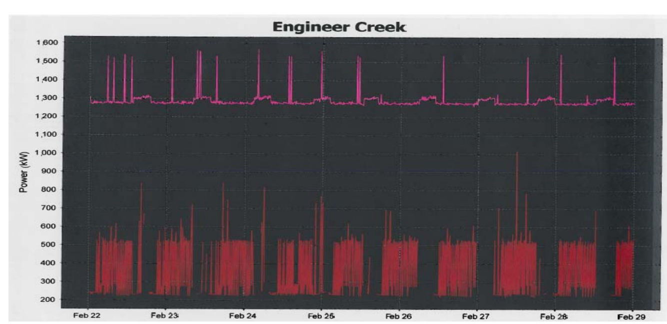
C. Battery

In the case of a Cycle-Charge system, the battery is a crucial component in the power system. Energy produced by the generator and/or renewable energy components is stored for use by the telecom load and support systems (heat, lights, ventilation, etc). Without a reliable battery, the power system becomes very inefficient. The more battery capacity, the better, given space limitations, of course.


Parallel 48V BAE 1500 a/h, tubular positive, gelled electrolyte batteries

D. Typical Site Load Profile

For the purposes of this research, we picked a "typical" Cycle-Charge site load profile for the energy model. Site loads include 1300 – 2000 watts of radio/electronics operating at a steady state, and cyclical AC loads (fed from the DC/AC inverter) ranging from 250 – 600 watts. The average continuous load is approx 2000 watts.



Site AC (red) & DC (purple) load profile, 7 day period, Feb 2012

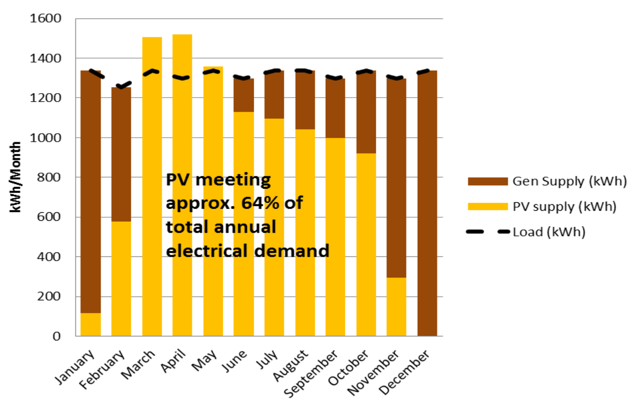
3. HYBRID DIESEL/SOLAR POWER SYSTEM

A. *Design Considerations*

A feasibility study of the effectiveness of adding a PV array to and existing microwave repeater site was completed for Northwestel by the Yukon governments Energy Solutions Center. Several energy production models were examined based on the array size, which fed into a business model, which compared the capital cost of the PV system to the savings that could be realized. As with all power projects, there were many variables to consider, including:

- Capital cost of PV system
- Energy production target for PV
- Physical space available for PV array
- Physical space available for batteries
- Seasonal variations of available PV energy

Due to the extreme variation in the available solar energy throughout the year, we knew we could not reasonably expect to power the site completely with PV energy, so we had to make a sizing decision based on a "reasonable" energy target, and the constraints we faced with capital funding and physical space restrictions for both the PV array and batteries. Several analytical tools were used to aid in the decision making process:

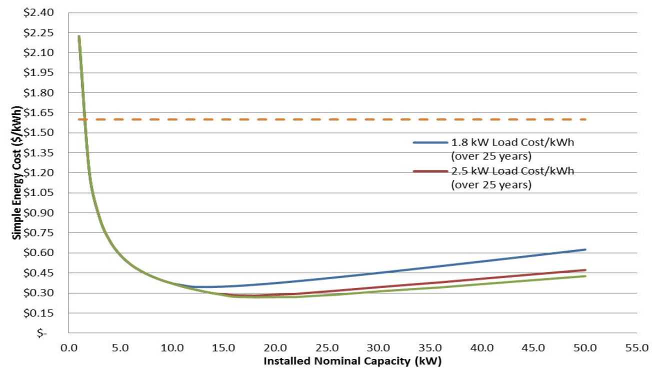


PV energy availability by month – 15 kW array[i]

			1.8 kW Site Load			2.5 kW Site Load			2.8 kW Site Load		
PV Syste Size (kW installed)	PV System Cost	Avoided Diesel Cost (Current Price $/kWh)	PV Energy Cost* ($/kWh)	Savings ($/year)	Simple Payback	PV Energy Cost* ($/kWh)	Savings ($/year)	Simple Payback	PV Energy Cost* ($/kWh)	Savings ($/year)	Simple Payback
10.0	$ 80,275	$ 1.60	$ 0.37	10,599	7.57	$ 0.37	10,599	7.57	$ 0.37	10,599	7.57
11.0	$ 83,723	$ 1.60	$ 0.36	11,603	7.22	$ 0.35	12,005	6.97	$ 0.35	12,005	6.97
12.0	$ 87,163	$ 1.60	$ 0.35	12,607	6.91	$ 0.33	13,411	6.50	$ 0.33	13,411	6.50
13.0	$ 90,596	$ 1.60	$ 0.34	13,187	6.87	$ 0.31	14,928	6.07	$ 0.31	14,928	6.07
14.0	$ 94,023	$ 1.60	$ 0.35	13,649	6.89	$ 0.30	16,445	5.72	$ 0.30	16,445	5.72
15.0	$ 97,444	$ 1.60	$ 0.35	14,019	6.95	$ 0.29	17,591	5.54	$ 0.28	18,083	5.39
16.0	$ 100,861	$ 1.60	$ 0.35	14,316	7.05	$ 0.28	18,737	5.38	$ 0.27	19,721	5.11
17.0	$ 104,274	$ 1.60	$ 0.36	14,553	7.16	$ 0.28	19,501	5.35	$ 0.27	20,569	5.07
18.0	$ 107,684	$ 1.60	$ 0.36	14,743	7.30	$ 0.28	20,265	5.31	$ 0.27	21,416	5.03
19.0	$ 111,090	$ 1.60	$ 0.37	14,894	7.46	$ 0.28	20,600	5.39	$ 0.27	22,028	5.04
20.0	$ 114,494	$ 1.60	$ 0.37	15,011	7.63	$ 0.29	20,935	5.47	$ 0.27	22,640	5.06
21.0	$ 117,895	$ 1.60	$ 0.38	15,100	7.81	$ 0.29	21,269	5.54	$ 0.27	23,252	5.07
22.0	$ 121,294	$ 1.60	$ 0.39	15,166	8.00	$ 0.29	21,604	5.61	$ 0.27	23,864	5.08
23.0	$ 124,690	$ 1.60	$ 0.40	15,211	8.20	$ 0.30	21,645	5.76	$ 0.27	24,046	5.19
24.0	$ 128,085	$ 1.60	$ 0.40	15,239	8.41	$ 0.31	21,686	5.91	$ 0.28	24,227	5.29
25.0	$ 131,478	$ 1.60	$ 0.41	15,252	8.62	$ 0.31	21,727	6.05	$ 0.28	24,409	5.39

*PV Energy Costs are agrigated over a predicted 25 year project lifespan

Savings/Payback calculator



Energy cost/kWh calculator – orange dashed line is diesel generator cost

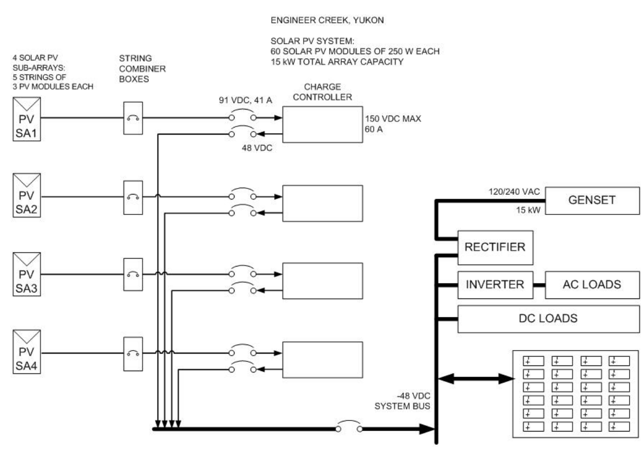
In the end, we chose a nominal 15 kW PV array, as a compromise between cost, physical size, and energy output. Our energy target was to produce between 60 – 70% of the sites energy requirement with PV, with the remaining 30 – 40% being supplied by the diesel generators.

At this level of PV power production, our business case predicted a simple payback on investment within 6 years, and more or less found the "sweet spot" of cost and performance. Producing energy at remote sites, where fuel costs are high and continue to increase, is a challenge. The long-term benefit of installing PV is obvious, the blended cost power per kWh is greatly reduced compared to the "diesel only" system.

B. *System Design and Components*

Gordon Howell, of Howell-Mayhew Engineering Inc was engaged to design and install the 15 kW PV array selected for our Engineer Creek site. The PV system was integrated into the existing power system, and consisted of the following equipment:

- 60 - Conergy 250 watt panels
- 4 - Combiner boxes c/w circuit breakers
- 2 - Quad boxes c/w circuit breakers
- 4 - Morningstar Tristar MPPT charge controllers
- 1 – 400 Amp disconnect
- Panel Mounting frames and foundation materials
- Data logging equipment & camera



Schematic of PV Engineer Creek Diesel/PV hybrid power system[ii]

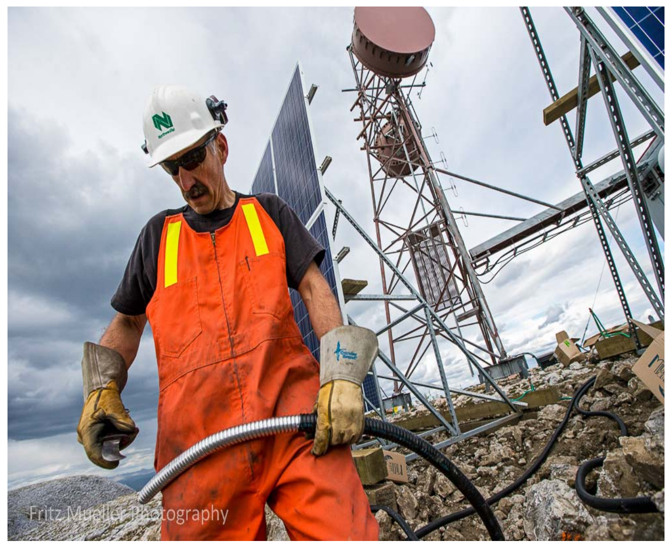
C. System Installation

Materials, construction equipment, and installation crew were transported to the site via helicopter. Due to the limited lifting capacity of the helicopter, equipment size was kept to a minimum. The foundation and panel mounting structure we designed to be modular, using materials that could be positioned by hand. Rock bolts were used to pin the foundation to the mountain top. To minimize the footprint of the array, 2 rows of panels in vertical orientation were attached to the preassembled frames. Limited site space and rough terrain forced us to install the PV sub-array sections in a less than optimal arrangement, but compromises were dictated by site conditions.

Small excavator being lifted to site

Holes being drilled into bedrock for rock bolts

Foundations & frames complete, panels being installed



Wiring underway

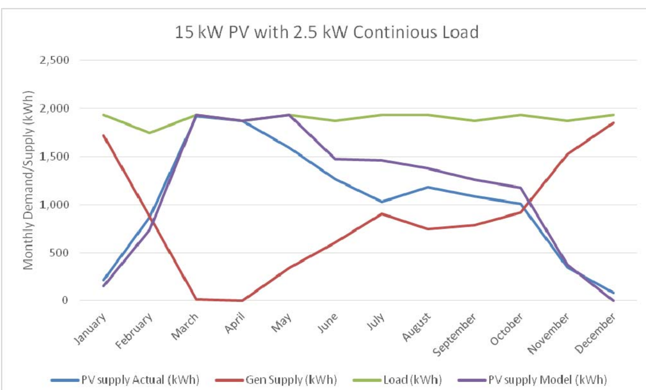

Installation complete, Engineer Creek, Yukon, (Lat 65’-18” N) 2013

D. System Performance

Data logging equipment was installed to monitor the performance of hybrid diesel/solar power system, along with a sensor to record outside air temperature. Data readings were recorded every 10 minutes. As well, we installed a camera to observe the PV array, allowing us to correlate site conditions to performance. The camera has been quite useful in understanding the conditions that affect PV system performance. A picture is taken every hour and stored on the "data cloud" website.

Our primary goal in gathering the performance data of the power system was to validate the accuracy of the "simulation" prepared using "PVSYST" software. The simulation was used to prepare the business case to support the Capital expenditure on the addition of the PV system, so the accuracy of the simulation is critical to future of the program. If we cannot demonstrate that we can accurately predict the amount of energy that will be produced, leading to operational savings in diesel fuel, no more funding will be forthcoming.

The following graph illustrates the performance of the system, compared to the software simulation:



Actual PV supply (blue) versus predicted supply (purple)

As you can see, the actual results did match up with the simulation as close as can reasonably be expected. Overall, our expectation of approx 60% supply by PV is on track, giving us a simple payback on investment within 5 – 6 years, which is an acceptable rate of return for our organization.

4. TECHNICAL ISSUES & LESSONS LEARNED

A. Shading

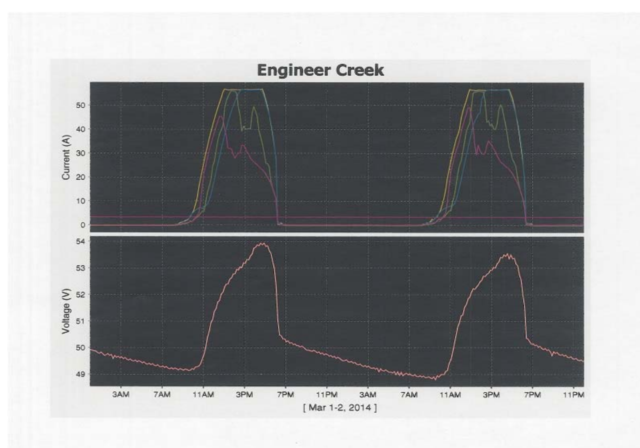
Due to limited space on our site lease, and the rough topography, we located the PV sub-arrays where they could fit, with the best southerly orientation possible. This led to less than optimal placement of one of the sub-arrays, which caused shading of an adjacent sub-array when the sun is low in the sky. As well, a snow drift built up in front of two of the sub-arrays, which caused shading, again when the sun was low in the sky (Nov – February). The shading issue was largely gone by mid-March, as the sun rose higher in the sky and the snow began to melt. Sub-array output is reduced by at least 50% with partial shade on any panel connected in series, so the output reduction is substantial.

Shading from snow drift & other sub-array when sun is low in the sky

Shading issue less prevalent by mid-March

B. Sub-array orientation

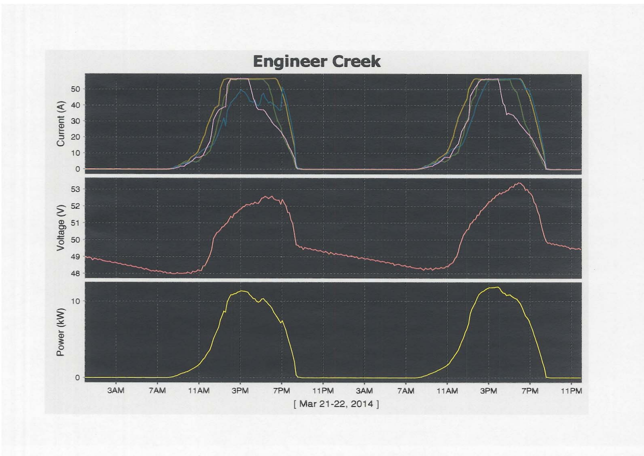
Sub-array #3 was positioned facing a bit south-west due to the rough terrain encounter on site. This caused the output from this sub-array to lag behind the others in the shoulder seasons (November – February). Later in the spring as the sun set further in the West, this issue goes away, as the SW facing sub-array generates power later in the day.



Shading effect, (green & red sub-arrays) orientation effect (blue sub-array)

C. Number of Charge Controllers

Our 15 kW, 60 panel system was split into 4 sub-arrays, each with 5 strings of 3 series connected panels feeding 4 individual charge controllers. Each charge controller is rated at 60 amps, and will "current limit" to remain below that level. The controllers also "voltage limit" at 55 volts, therefore the maximum output from each sub-array is around 3 kW, giving us a total of approx 12 kW of maximum output.



Power output limited to 12 kW by charge controller current regulation

It should be noted that 100% of the site energy was provided by the PV system in March and April, so this reduction in total power output by the charge controllers in "current limit" is not a big factor in overall energy production.

D. Panel Icing

Our panels were mounted vertically in an attempt to reduce or eliminate the accumulations of ice and snow. Although this may not be the "optimum" angle, it is a very effective strategy to stop ice/snow from collecting. It is also an efficient angle when the sun is low in the sky. We found no accumulations through the winter; even if the panels would frost over during the night, they would melt off, even in -30 deg C conditions. The heat from the sun would slowly dissipate the frost, and very little production was lost.

E. Lessons Learned

To fully realize the 15 kW of installed capacity, we need to add a 5th charge controller and reduce our 3 panel strings from 5 to 4 per sub array. This will reduce the current to each controller, increase total current potential, and allow the maximum output when conditions are right. It is well known that cold weather increases the efficiency of solar panels, so we need to take advantage of this effect.

Shading is a major issue affecting output of the panels, and every effort needs to be made to avoid it.

Panel orientation is very important in the shoulder seasons when we need to gather as much energy as possible. Even a few degrees off the optimum orientation will reduce the amount of energy harvested.

A vertical orientation of the PV array was confirmed to be effective in eliminating ice/snow/frost build up.

5. SUMMARY AND NEXT STEPS

A. Summary

Our initial experience with the diesel/PV hybrid system at Engineer Creek site was very encouraging. In spite of some technical issues, we came close to our target for energy production by the PV system. We were able to reduce the amount of fuel normally burned to operate the site by nearly 60%, which is very good news.

The accuracy of the modeling software has been confirmed, therefore we are confident that we can reasonably predict the amount of energy that we can harvest throughout the year, and apply this estimate to a business case to secure funding for further deployment of the hybrid diesel/PV power systems.

Not only has this system reduced operating costs, it has also reduced our impact on the environment. It is a good sign that there is harmony in the world when a herd of caribou wander by the site powered by PV energy, no noisy diesel engine to disturb their travels; the sounds of silence!

Caribou feeding at the Engineer Creek site

B. Next Steps

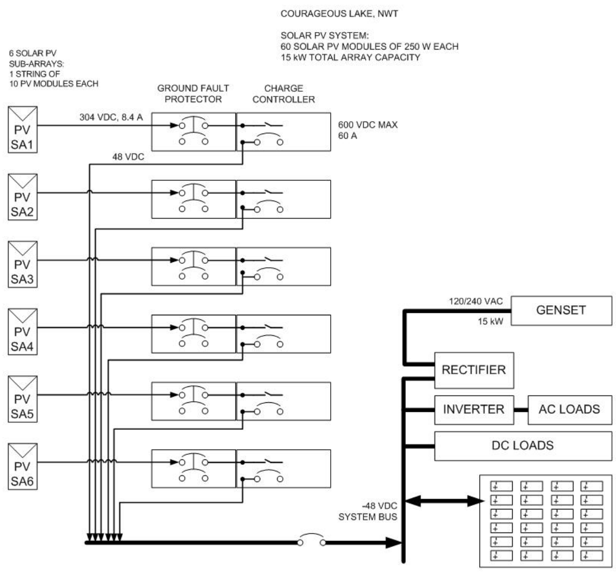
With success at our pilot project site, funding was allocated for 4 more diesel/PV hybrid systems in 2014. We have incorporated the "lessons learned" into the new design, which we expect will perform better than the initial system. Shading, orientation, and the number of charge controllers have all been addressed in a new design.

As well, we are using a new charge controller offered this year by Morning Star; the TriStar MPPT 600V. This charge controller operates at a much higher voltage, which allowed us to simplify the design in several ways:

- 10 panel strings, operating at >300 VDC, allow us to reduce wire size from array to controller
- Elimination of combiner boxes at each sub-array
- Elimination of quad box
- addition of a ground fault protector coupled to the charge controller, c/w disconnect breaker

These refinements to the system made for a simpler, cleaner system, requiring less material and less time on site

for installation. This has reduced the installed cost per watt, improving the business case for the addition of PV at more locations.



Schematic of PV Engineer Creek Diesel/PV hybrid power system

With 6 charge controllers, will fully realize the 15 kW output rating of the arrays, and potentially more when the temperatures are low and sunlight is reflected off the snow onto the panels. In these conditions, array output can increase by 20%, so we will likely see total output > 18 kW.

A continuation of our program to install PV systems at existing sites is planned for 2015 and 2016, with engineering & planning currently underway for 8 locations. As well, a new site under construction will incorporate the diesel/PV hybrid power system as our new "standard" off-grid power system.

Courageous Lake, NWT, (Lat 64'-14" N), - 15 kW PV installation, 2014

MacKay Lake, NWT, (Lat 63'-47" N), - 15 kW PV installation, 2014

Weasel Lake, Yukon, (Lat 61'-52" N) - 10 kW PV installation, 2014

McEvoy Lake, Yukon, (Lat 61'-45" N) - 10 kW PV installation, 2014

---

[i] Northwestel Remote Station Solar/Diesel Hybrid Feasibility, prepared by the Yukon Government's Energy Solutions Centre, 2013

[ii] Gordon Howell, Howell-Mayhew Engineering Inc